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ABSTRACT

This paper describes the effects of the implementation of constructivist techniques with interactive computer simulations on conceptual understanding of plant nutrition and critical thinking skills in heterogeneously grouped secondary biology classrooms. The study focused on three strategies for teaching plant nutrition: (1) traditional; (2) constructivist; and (3) computer-facilitated. This paper outlines the results on student learning as well as emergent issues concerning implementing technological and pedagogical innovations in high school science classrooms. Results indicated that post-test gains were the greatest for the traditional class followed by the constructivist class, indicating that the traditional class learned the more traditional content. Video data indicated that the students spent significant amounts of time trying to understand the nature of the computer model and how to operate the software. Observations also indicated that there was no closing discussion to help students connect what they learned on the computer to what they had learned from other activities in the class. It was concluded that since there was no significant difference among the post-test gain, open-ended scores, and The Critical Thinking in Biology (TCTB) test, it might be implied that each strategy is as effective as the other in promoting conceptual change and critical thinking skills. Contains 29 references. (JRH)

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Effects of Constructivist and Computer-Facilitated Strategies on Achievement in Heterogeneous Secondary Biology

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Abstract

This paper describes the effects of the implementation on conceptual understanding of plant nutrition and critical thinking skills in heterogeneously grouped secondary biology classrooms. Plant nutrition includes basic concepts in secondary biology that are difficult for students to comprehend. (Johnstone and Mahnoud, 1980; Finley, Stewart and Yarroch, 1982). After instruction, students often continue to express alternative ideas and incomplete understanding of plant nutrition (Bell and Brook, 1984; Stavy, Eisen and Yaakobi, 1987). Building upon a comparison of traditional and constructivist classrooms compiled by Brooks and Brooks (1993), we focused on three strategies for teaching plant nutrition: traditional, constructivist, and computer-facilitated. We outline the results on student learning as well as issues that have emerged on implementing technological and pedagogical innovations in high school science classrooms.

Background

Beyer (1988) defines the ability to think critically as the skill to analyze any claim, source, or belief precisely, persistently, and objectively, and to judge information for its accuracy, validity and worth. Critical thinking skills may be vital components of constructivist-oriented and technological innovations that shift the focus toward student participation in directing science investigations. Heterogeneous grouping, cooperative learning, experiential learning, and learning-cycle implementations all show indications of improving critical thinking skills (Ramsey and Howe, 1969a,1969b; Tomlinson-Keasey and Eisert, 1977; Collea and Nummedal, 1979; Johnson and Johnson, 1979; Johnson et al., 1984). Less is known of the role of technology. Rivers and Vockell (1987), applied computer simulations that combined text and graphs to investigate the dependence of learned thinking skills on the guidance given to high school biology students as they conducted simulated experiments. Students given strategies to use the simulations scored higher on tests of critical thinking and scientific thinking than those who simply had access to simulations or no access at all.

Two studies of constructivist classrooms (Barker and Carr, 1989; Oldham, Driver and Holding, 1991) indicate that students develop a better understanding of the processes of photosynthesis and plant respiration. Using a social-constructivist framework, Lumpe and Staver (1995) applied peer collaboration techniques that developed in their students "more scientifically correct conceptions of photosynthesis than did students working alone." Smith, Snir and Grosslight (1992) used the conceptual change guidelines of Strike and Posner (1985) to build upon middle school students pre-instructional and intuitive understanding. They found that a combination of real-world phenomena and explicit computer representations of the phenomena was necessary to promote conceptual understanding of weight and density (Snir, Smith, and Grosslight, 1993).

In a recent project to develop simulations for teaching special relativity to high school physics students, Horwitz and Barowy (1994) created a model of instruction that included cognitive and affective considerations along individual and social dimensions. They employed simulations for the visualization of relativistic phenomena, together with a collaborative cognitive dissonance (paradox) strategy in which the students negotiated the meaning and resolution of paradoxes. They administered an instrument of conceptual understanding developed by Villani and Pacca (1987) in which their high school subjects performed better than physics graduate students taught traditionally.

Research Questions

Two research questions focus our investigations. We investigated the following hypothesis: The combination of constructivist techniques with interactive computer simulations should improve achievement, defined by critical thinking skills and conceptual change. For simplicity, we define "computer-facilitated" to mean constructivist-oriented with the inclusion of interactive computer simulations.

1. How do three treatments, traditional, constructivist and computer-facilitated, compare for promoting conceptual understanding of plant nutrition?

2. How do three treatments, traditional, constructivist and computer-facilitated, compare for promoting critical thinking skills?

The traditional science classroom instruction is characterized by a fixed, fact based curriculum, didactic teaching, individual student work, and pen and paper assessment. The curriculum is textbook based. Activities include the use of student worksheets, lectures and students home assignments with little or no group interactions.

The constructivist science classroom is characterized by a flexible, concept based curriculum, student centered learning, hands-on activities, group work, and ongoing alternative assessment (Brooks and Brooks, 1993) In a computer-facilitated constructivist classroom, computers integrated into the curriculum provide additional

support for planning and designing experiments, investigating theoretical models of phenomena, data analysis and the coordination of experimental data with theoretical models.

The traditional classroom provides baseline observational data and benchmarks for evaluating the overall effectiveness of the constructivist approaches, as the constructivist approach provides a benchmark for the computer-facilitated approach. The context for each research question is the heterogeneous secondary biology classroom. We have not made this choice to resolve the debate between similar and mixed ability grouping, but rather to embed this study within conditions that are typical of many schools.

Method

This experiment centers on the teaching of plant nutrition in three heterogeneously grouped classrooms, traditional, constructivist and computer-facilitated. The study involved a suburban rural, middle class high school that offers heterogeneously grouped biology, with the exception of honors students. Most teachers in the school have little experience with using computers in their classroom. Generally, students in this school are not skilled in the use of computers in the classroom. While the school philosophy is one that advocates instructional change, the location of the school is far from local educational research institutions, isolating it from the influences of those institutions.

One teacher implemented three different instructional approaches in three different classrooms. The teacher has more than 25 years of science teaching experience, yet this is the first time he has been involved in a research study. The instructor was trained on administering the pre-test, and post-tests, and teaching the plant unit. Investigators visited the classrooms and observed and videotaped the teaching and learning process, providing minimal interference.

Each class meets every other day for ninety minutes. The traditionally taught class consisted of 20 students, the constructivist class consisted of 14 students, and the computer-facilitated class included 22 students. The plant nutrition conceptual understanding test was administered as a pretest and a posttest to all classes at the beginning and the end of the plant nutrition unit. The Critical Thinking in Biology test was administered at the conclusion of the teaching unit. Two essay questions were administered to the students as part of their midyear exam.

The traditional approach is based on the Miller and Levine's (1995) Biology textbook generated unit on plant nutrition. Classroom instruction is characterized by a fixed, fact based curriculum, didactic teaching, individual student work, and pen and paper assessment. Activities include student worksheets, lectures and student textbook assignments with little or no group interactions.

The constructivist approach follows the constructivist teaching sequence described by Driver and Bell (1986) and detailed in the Children's Learning in Science Project's (CLIS) Approaches to Teaching Plant Nutrition (1987). Activities in the constructivist are student directed and involve students working cooperatively in groups.

The computer-facilitated approach substituted an interactive simulation model of plant nutrition (Explorer: Photosynthesis, LOGAL software) in place of teacher-centered presentations of the school science view in the CLIS unit. We delineate this treatment more fully because it has not been described in the literature. The software replaced the lecture in order for students to learn the topic through their own interactions with explicit visual and dynamic representations of the biological concepts and phenomena, rather than through more passive listening. Students interacted twice with the simulation while working on written activity sheets that guided their investigation with the software.

In the first activity, students were first introduced to the software, then guided through an exploration of plant nutrition conditions, products and reactants, and main concepts and terminology. Students were asked to make predictions prior to changing levels of CO_2, H_20 and light, to test their predictions. Students' investigations were focused by a written activity adapted from those included with the software.

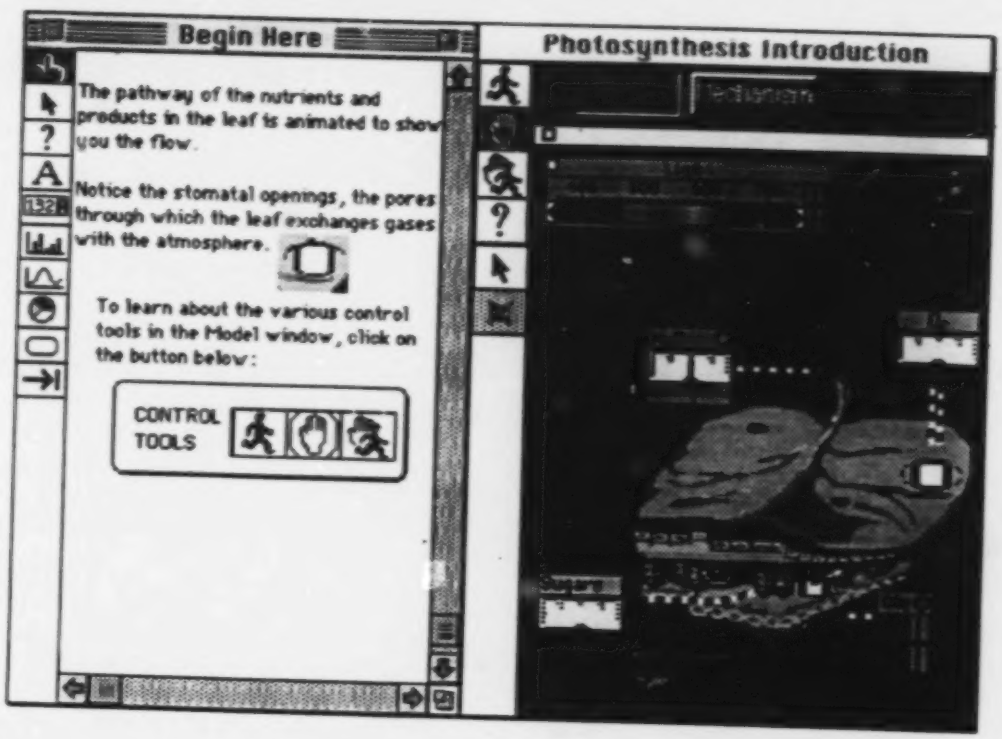
Begin Here
The pathway of the nutrients and products in the leaf is animated to show you the flow.
Notice the stomatal openings, the pores through which the leaf exchanges gases with the atmosphere.
To learn about the various control tools in the Model window, click on the button below:
CONTROL TOOLS
Photosynthesis Introduction

Figure 1. The initial display for the first activity represents the function of a leaf.

In the second activity, students were introduced to products, reactants and conditions surrounding the light and dark reactions using a display that explicitly represented the underlying mechanisms of the reactions (Otto and Towle, 1977). Students worked cooperatively or alone according to their preferences. They were given a written activity sheet to focus their investigations. They were asked to make predictions, draw graphs of reactant rates vs. environmental conditions, and draw

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systems diagrams that related products, reactants and environmental conditions (Roberts, 1977).

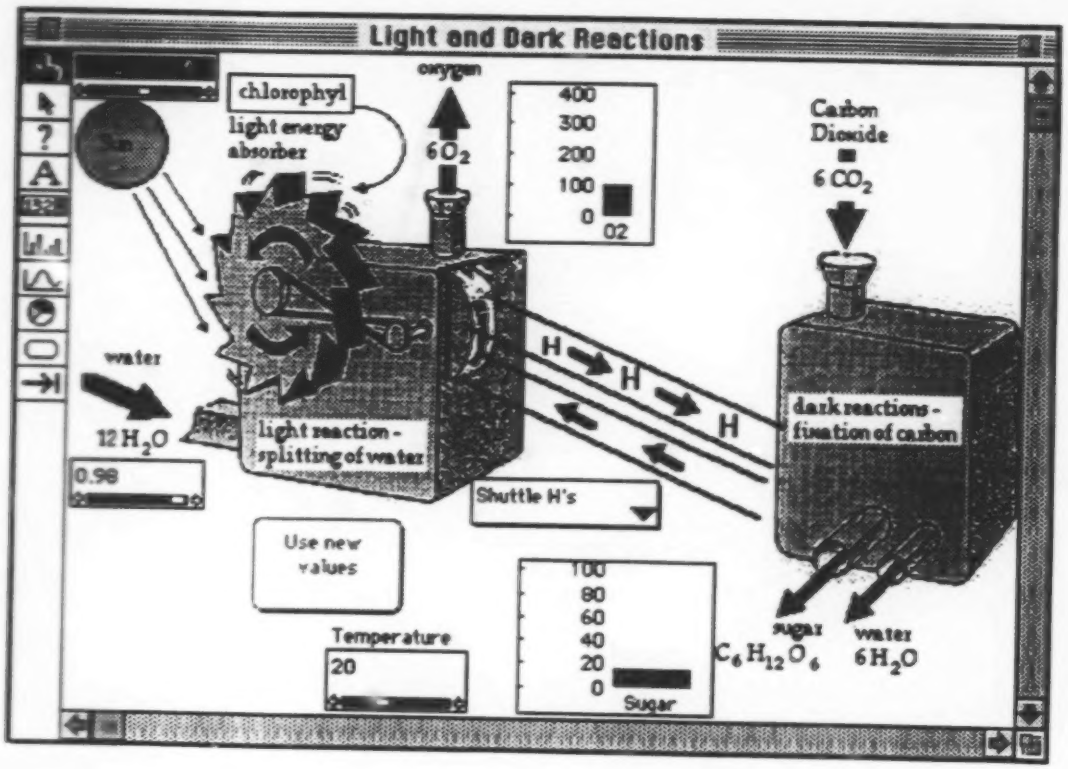

Figure 2. The display for the second activity represents the light and dark reactions.

Assessment

Pre-and post-tests of conceptual understanding of plant nutrition consist of the multi-tier multiple choice test developed by Haslam and Treagust (1987). The test consists of 13 items with a reliability of 0.72 (Cronbach's coefficient alpha) and a readability between 7 and 8 year level (Fry's Readability Graph). Each item consists of two parts; a content question and a reason question. We scored the test on a total of 26 questions. A correct response to the content question and the reason question was worth 2 points. A correct response to the content question but an incorrect response to

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the reason question received one point. An incorrect response to the content question and a correct response to the reason question received 0 points.

The plant nutrition portion of The Critical Thinking in Biology Test (TCTB) is used to assess the critical thinking skills of the students. The alpha coefficient for TCTB is 0.83. Concurrent validity of TCTB is supported by r values of 0.68 and 0.64 with the Natural Science section of the ACT test and Watson and Glasser's Critical Thinking Appraisal test (McMurray, Beisenhorz, and Thompson, 1991). We developed an additional test of two open-ended to assess further students understanding of the variables involved in photosynthesis and the relationship between the light reactions and dark reactions. This test asked the students to synthesize their knowledge of the topic in essay form with the option of drawing diagrams or pictures. Questions were scored by one of the researchers and an experienced biology teacher not participating in the study. A test of inter-rater reliability was applied with a reliability of 0.8.

The unit of analysis is the biology classroom. Class results are reported and analyzed using analysis of variance (ANOVA).

Results

The pretest showed no significant difference between the three classes indicating that the three classes were similar with regard to their background knowledge of plant nutrition before the classroom treatments. Therefore we applied a one-way analysis of variance (ANOVA) on all tests with an alpha of 0.05. The ANOVA results for the conceptual change pretest, posttest, posttest gains, critical thinking test (TCTB) and are summarized in Table 1.

Post-test, post-test gains, Critical Thinking in Biology test, and the open ended instrument showed no significant difference between each group.

An analysis of variance of pretest and post test scores showed a significant difference for the traditional and constructivist class. No significant difference was seen in the computer-facilitated class (Table 2)

Table 1

Mean, Variance and F Values on Student Academic Outcomes

	Constructivist	Traditional	Computer Facilitated	F	P
Pretest	0.41 (0.01)	0.43 (0.03)	0.43 (0.03)	0.04	0.29
Posttest	0.51 (0.01)	0.58 (0.03)	0..49 (0.04)	1.33	0.28
Posttest Gains	0.10 (0.03)	0.15 (0.04)	0.06 (0.03)	1.13	0.33
TCTB	0.20 (0.01)	0.24 (0.02)	0.30 (0.03)	2.48	0.09
Open Ended	1.88 (1.02)	1.78 (0.85)	1.98 (1.00)	0.42	0.66

Table 2

Analysis of Variance on the Pre-test and Post-test Scores for each Class

Class	F	F_{crit}
Constructivist	4.67	4.26
Traditional	7.05	4.15
Computer Facilitated	1.16	4.13

Discussion

Overall, it appears that none of the three classes learned plant nutrition content or thinking skills more than any other class. In three separate measures, the test of conceptual change, and the two items on the instrument we designed, one of the three classes had a superior, though barely significantly so, score. It is plausible that the shifts

in learning result from the different emphasis in each class. This is consistent with Rivers and Vockell (1987) who found the impact of simulations to vary according to the nature of the content and thinking skills being measured.

Post-test gains were the greatest for the traditional class followed by the constructivist class, indicating that the traditional class learned the more traditional content. These higher test scores may be explained by the nature of the conceptual change post test. Half of the items on the conceptual change test are fact-based content questions. Video data, lesson plans and activities indicate that the traditional class was more fact oriented. It is no surprise that students who are taught in a traditional fact based manner would score higher on this type of assessment.

Out of the two constructivist classes, the computer-facilitated class performed less well on the test of conceptual change. We believe an important difference between the two classes is that students in the simulation class learned by interacting with the simulation, whereas the other class learned by teacher lecture. Despite the greater interactiveness of the simulation, the type of knowledge built into the underlying model embodies only content. In contrast, the teacher with years of experience brought to bear pedagogical knowledge of what topics students find difficult, and has personal knowledge of each student's personality and prior performances. This knowledge was drawn upon to make decisions about how to respond to student questions. The types of questions that students can ask of a teacher are very different from the types of questions that students can ask of themselves using a computer model, which responds only according to how well it is programmed to represent and replicate the real phenomena.

Smith, Snir and Grosslight (1992) have pointed to the advantage of explicit computer representations of the phenomena to promote conceptual understanding. We provided explicit representations during both simulation activities, including

simulation displays as well as student-drawn system diagrams. No effects from these additional measures are apparent in our instruments. In particular, even though students were prompted to express their understanding with the option of using diagrams in the open-ended instrument, none appeared in any of the students' explanations.

An important dimension is how much technology the students were learning in place of skills and content. We find in our video data that students spent significant amounts of time trying to understand the nature of the computer model and how to operate the software. Clearly students who were more fluent with the technology would have spent greater time thinking about plant nutrition and may have performed better on the tests.

Our observations also indicate there was no closing discussion to help students connect what they learned on the computer to what they had learned in other activities in the class. Smith et al. (1992) and Richards and Barowy (1992) point to the close integration of the activities as a precursor to success. Other studies on simulation and conceptual change spend a much greater time introducing the software to students, in training teachers, and in students' interactions with the software. In contrast, we have attempted to reproduce conditions similar to those under which many teachers might experiment with curriculum and using computers in their classes (Barowy and Laserna, in press). The two exposures to the computer simulation are well within the type of effort possible for a teacher who is experimenting with technology and pedagogic approaches.

Finally, there is a significant question about whether the teacher was able to adhere to the constructivist approaches without personal commitment to the epistemology per se. Our observations indicate that the teacher involved in the study was able to change classroom behaviors according to the prescribed instructional strategy.

We find that since there was no significant difference among the posttest gain, open ended scores and the TCTB, one might infer that each strategy is as effective as the other in promoting conceptual change and critical thinking skills.

Implications

Future research studies on computer-facilitated learning should include analysis of the quantity and quality of student-student, student-teacher and student-computer interactions. Any study that includes implementation of technological innovations in the classroom should incorporate more time for the students and teacher to become comfortable with the technology. In this way results can focus on the particular skills and content to be assessed and not be confounded with the learning of the technology.

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Notes

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Constructivist Strategies in Secondary Biology

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